SOLAR RADIATION IN MIDDLE NORTH GERMANY ACCORDING TO MEASUREMENTS AT POTSDAM

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By JOHANN SCHUBERT

The intensity of solar radiation at the surface of the earth is determined by the intensity at the outer limit of the atmosphere and by the loss sustained in the path through the air even when the sky is perfectly clear.

The amount of heat which the unit surface receives in the unit of time with normal incidence of the sun's rays is called full radiation, intensity in the direction of the sun's rays, or total intensity. The radiation upon a surface whose normal forms an angle with the direction of the rays, or the radiation component in the direction of this normal, follows from projection.

Calculations of the solar radiation for different latitudes and also for surfaces with different slope and exposure (*Himmelsrichtung*) are often undertaken without reference to the atmosphere and, at times, even without regard to the changing distance of the sun under the simple assumption, which by no means corresponds to fact, that the full radiation is constant at the bottom of the sea of air. Eser [1] calculated for the latitude of Munich the duration and daily totals of radiation on planes of different slope and exposure taking as a unit radiation at normal incidence for the period of one hour. Others [2] have developed similar formulas or graphic methods. Recently Gessler [3] has renewed and extended such calculations, and Hopfner has published as a supplement to an older work [4] a voluminous, orderly, and highly commendable prize paper on solar radiation [5] in which the sun is assumed to be a point-like source of light with constant energy and the earth is considered as having no atmosphere.

In order to take account of the depletion of solar radiation [6] in the earth's atmosphere it has been assumed, after the example of Lambert (1726), that in the passage through equal air masses the radiation is diminished to the same fractional part, which holds, to be sure, only for homogeneous radiation. Especially through the work at the American observatories, which are thoroughly equipped and favorably located (some at great elevation above sea level) has it become possible to determine the degree of transmissibility of the different wave lengths, to take account of the influence of water vapor and dust, and to determine accurately, to within 1 per cent, in absolute quantity the mean intensity of the solar radiation outside the earth's atmosphere; that is, the solar constant.[7]

By careful, extensive observations at a series of places the actual solar radiation at the earth's surface has been determined for different elevations of the sun and different seasons. Through the exact measurements of W. Marten at the Potsdam Observatory during the period 1907 to 1923 there has been determined the daily and yearly march of solar radiation in middle North Germany, which forms a reliable basis for further investigation.

The question of the radiation on surfaces of different slope and exposure can now be answered unequivocally. The values of full radiation with cloudless sky presented in this paper are taken from W. Marten's work, *Das Strahlungsklima von Potsdam.*[8] Berlin, 1926. For the declination of the sun (δ) values are taken from the *Nautisches Jahrbuch* for 1925; such values agree well with the average for the period of observation. The latitude of Potsdam (φ) is 52° 23′; the hour angle (t) is counted from noon. The point of observation lies (since 1909) about 106 meters above sea level and about 25 meters above the ground.

We resolve the full radiation, or total intensity, J, into a vertical component Z (directed downward from the zenith) and a horizontal component or intensity H; the latter is resolved into a south component (intensity of radiation from south to north) X and a west component Y. Denoting the sun's elevation by h and its azimuth by A, we have [9]

$$H = J \cos h.$$
$$X = J \cos h \cos A = J\ (-\sin \delta \cos \varphi + \cos \delta \sin \varphi \cos t).$$
$$Y = J \cos h \sin A = J \cos \delta \sin t.$$
$$Z = J \sin h = J\ (\sin \delta \sin \varphi + \cos \delta \cos \varphi \cos t).$$

These formulas give radiation for the following surfaces: X, south wall; Y, west wall, and Z, horizontal plane.

The radiation on any plane whatever or the intensity in the direction of its normal can be constructed from these components, for example:

Southeast wall, $(X-Y) \cos 45°$.

South slope of 30°, $X \sin 30° + Z \cos 30°$.

Southeast slope of 20°, $(X-Y) \cos 45° \sin 20° + Z \cos 20°$.

The values of full radiation with cloudless sky are calculated symmetrically with reference to true noon by taking together each of the two hours equidistant from noon. A preliminary investigation to determine the finer differences between forenoon and afternoon was made by Marten (*Das Strahlungsklima*). According to that the highest values shift to the forenoon in summer and to the afternoon in autumn by an hour or less.

The values of solar radiation on cloudless days are multiplied by the duration of sunshine to obtain the radiation values with mean cloudiness. In addition values for the middle point of time were calculated from the sums of the duration of sunshine for four adjacent hours m_0, m_1, m_2, and m_3 according to the formula [10]

$$\frac{m_1+m_2}{2} + \frac{1}{6}\left(\frac{m_1+m_2}{2} - \frac{m_0+m_3}{2}\right).$$

Values for early and late hours were determined approximately; the recorded data on duration of sunshine were

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[1] Eser, C. Forschungen aus dem Gebiete der Agrikulturphysik, herausgegeben von E. Wollny, 1884, Bd. 7, p. 100; Zeitschrift der Österreichischen Gesellschaft für Meteorologie, 1885, Bd. 20, p. 71.

[2] Steiner, L. Meteorologische Zeitschrift, 1898, p. 193 and1906, p. 294; Zöllner, S. Meteologische Zeitschrift, 1906, p. 92. The intensity with normal radiation is considered constant.

[3] Gessler, R. Abhandlungen des Preussischen Meteorologischen Instituts, Bd. VIII, Nr. 1, Berlin. 1925. One equator-hour is taken as the unit of full radiation constantly received.

[4] Hopfner, F. Meteorologische Zeitschrift, 1906, pp. 384 and 396.

[5] Hopfner, F. Gerlands Beiträge zur Geophysik, 1926, Bd. 15, pp. 116 ff.

[6] Hann, Julius. Handbuch der Klimatologie, Bd. I, p. 93; Hann, Julius and Süring, R. Lehrbuch der Meteorologie, 4th edition, pp. 24, 801, 806.

[7] See papers on solar radiation (Sonnenstrahlung) listed in the index volume (1884-1908) of the Meteorologische Zeitschrift, also the following papers in that publication: Maurer, J., 1912, p. 561, and 1916, p. 193; Defant, A., 1913, p. 289; Fowle, F. E., 1914, p. 270; Hann, Julius, 1916, p. 79; Defant, A., 1916, p. 211; Kron, E., 1916, p. 228; Kimball, H. H., 1916, p. 377, and 1918, p. 144; Marten, W., 1920, p. 252; Ångström, A., and Dorno, C. 1921, p. 38; Dorno, C., 1922, p. 303; *Dietzius*, 1923, p. 161. Also *Sonnen*-und Himmelstrahlung in the indexes to theMeteorologische Zeitschrift for 1924 ff.

[8] Abhandlungen des Preussischen Meteorologischen Instituts, Bd. VIII, Nr. 4; Ergebnisse (d. Preuss. Meteorol. Inst.) 1908, p. XXIII and 1912, p. XI.

[9] Brünnow, F. Lehrbuch der sphärischen Astronomie, 4th edition, p. 81; Hammer, E. Lehrbuch der Trigonometrie, 2d edition, p. 511.

[10] Schubert, J. Der jährliche Gang der Luft-und Bodentemperatur. p. 32. Berlin. 1900.

supplemented by reference to measured values of radiation.

The paper then presents in tabular form [11] the values of radiation, in gram-calories per minute per square centimeter, with clear sky and with mean cloudiness received at Potsdam at each hour of the day at the middle of each month of the year on ten differently exposed surfaces as follows: Plane normal to the direction of the rays (total intensity), horizontal plane, walls facing north, east, south, and west, and slopes of 30° facing the above directions.

From values for clear sky there has been constructed for presentation here Table 1 showing values of radiation at 11 a. m., when the intensity of full radiation is only slightly below the maximum.

The maximum values of solar radiation with clear sky under different exposures are given in Table 2. It is to be noted that these values like those preceding relate to the middle of the month.

Table 3 (part of Table 5 in the original paper) gives solar radiation with average cloudiness, the actual radiation received, at Potsdam during one day at the middle of each month of the year.

Assuming that the mid-month values are average values for the month, Schubert presents a table of mean daily amounts of solar radiation received with clear sky and also with average cloudiness (at Potsdam) during the period from April to August, inclusive, which he calls the main growing season (*Hauptvegetationzeit*). These values which are of special interest to the agriculturist, are given in Table 4.

—*Selected text translated by W. W. R.*

TABLE 1.—*Solar radiation (gram-calories per minute per square centimeter) with clear sky at 11 a. m. at the middle of the month. Potsdam*

Exposure	January	February	March	April	May	June	July	August	September	October	November	December
Under normal incidence (total intensity)	0.98	1.11	1.11	1.26	1.28	1.27	1.19	1.15	1.21	1.16	0.97	0.93
On horizontal plane	.26	.45	.62	.90	1.04	1.08	1.00	.88	.77	.54	.30	.21
On east wall [1]	.24	.28	.29	.32	.31	.32	.29	.29	.31	.30	.24	.22
On south wall	.91	.98	.87	.82	.67	.58	.58	.68	.89	.98	.89	.88
On north slope of 30°	.00	.00	.10	.37	.56	.65	.58	.42	.22	.00	.00	.00
On east slope of 30° [2]	.34	.53	.68	.94	1.06	1.09	1.00	.91	.82	.62	.38	.29
On south slope of 30°	.68	.88	.97	1.19	1.24	1.23	1.15	1.11	1.11	.96	.71	.62
On west slope of 30° [3]	.10	.25	.39	.62	.74	.79	.72	.62	.51	.32	.14	.07

[1] On west wall at 1 p. m. [2] On west slope of 30° at 1 p. m. [3] On east slope of 30° at 1 p. m.

[11] Also in isopleths for radiation with clear sky.

TABLE 2.—*Maximum values of solar radiation with clear sky for different exposures (gram-calories per minute per square centimeter). Potsdam*

Exposure	Radiation in gr.-cal. min. cm.²	Month	Hour
Under normal incidence	1.278	May	Noon.
On horizontal plane	1.113	June	Do.
On north wall	.250	do	5 a. m.[1]
On east wall	.911	do	7 a. m.
On south wall [2]	1.019	October	Noon.
On west wall	.911	June	5 p. m.
On north slope of 30°	.654	do	Noon.
On east slope of 30°	1.156	do	10 a. m.
On south slope of 30°	1.276	May	Noon.
On west slope of 30°	1.156	June	2 p. m.

[1] Also 7 p. m. [2] 1.016, February, noon.

TABLE 3.—*Solar radiation (gram-calories per square centimeter), with average cloudiness, received daily at the middle of the month. Potsdam*

Exposure	January	February	March	April	May	June	July	August	September	October	November	December
Under normal incidence	84	134	226	354	441	489	414	375	329	212	95	70
On horizontal plane	20	44	102	196	276	319	269	223	165	81	25	15
On north wall	0	0	0	1	11	23	14	4	0	0	0	0
On east wall	13	29	61	106	133	148	122	112	91	49	17	10
On south wall	74	106	146	158	136	120	113	143	184	157	82	65
On west wall	14	29	56	99	126	139	121	106	88	49	18	12
On north slope of 30°	0	0	15	91	176	228	183	124	50	0	0	0
On east slope of 30°	18	42	96	182	251	289	240	204	153	76	24	14
On south slope of 30°	54	91	161	248	303	326	283	263	235	149	63	45
On west slope of 30°	19	42	92	175	245	281	239	198	149	76	25	15

TABLE 4.—*Mean daily total of solar radiation (gram-calories per square centimeter), with clear sky and with average cloudiness, April–August. Potsdam*

Exposure	Radiation in gr.-cal. min. cm.²	
	Clear sky	Average cloudiness
Under normal incidence	869	415
South slope of 30°	563	285
Horizontal plane	512	257
East slope of 30°	469	233
West slope of 30°	469	228
North slope of 30°	329	160

THE ROOT PROBLEM OF MACRO-METEOROLOGY

By DR. FRANZ BAUR

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SYNOPSIS

The root problem of macro-meteorology is the answer to the question: Are the changes in the system of the general circulation of the atmosphere, to which after all the great weather abnormalities are traceable, occurrences which originate in the main in themselves, or is their origin for the most part to be looked for outside the earth? The purpose of the following investigations is to help to pave the way to the right answer to this fundamental question. It is therein shown that it can not be proved that there is any connection between changes in atmospheric circulation and cosmic occurrences, especially solar ones; it is shown, however, that there is a close connection between these changes on the whole and the foregoing temperature and pressure abnormalities on the earth itself. Changes in solar radiation have an influence worth mentioning on the general circulation of the atmosphere only when they find a resonance in the complex wave system of atmospheric circulation.

We know that great weather phenomena (macro-phenomena, by which I understand, not the weather of single days, but the general character of the weather extending over a longer period, say of weeks and months) stand in closest relationship with the great variations in the general circulation of the atmosphere and their single parts. The idea of the general circulation of the atmosphere comprises in this connection a whole complex of phenomena, viz, the exchange of air between the